Bore Chatter Recognition using an In-Process Gage

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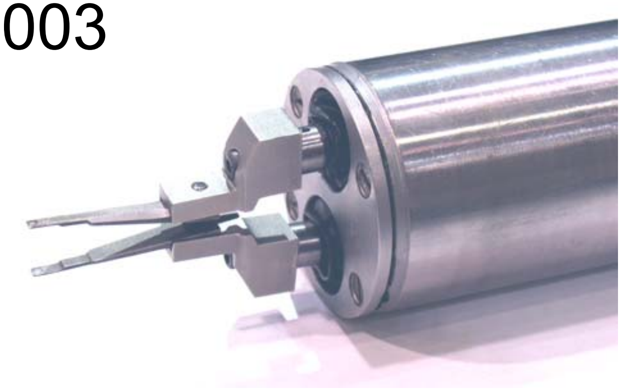
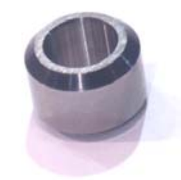
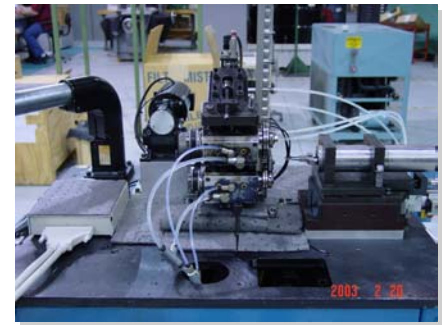


Problem Statement

- Valve tappets at Timken irregularly exhibit chatter after grinding of the bore
- Sample parts are taken from the manufacturing process and tested for chatter
- Currently, if chatter is detected the entire lot is inspected manually
  - A lot can consist of several thousand parts
  - Significant cost in terms of time and money
  - Reliability and repeatability of manual inspection is low



Research Objectives



- ❖ Develop a prototype machine that is capable of automatic chatter detection. The machine can be used as a post-process machine to sort out parts with chatter.

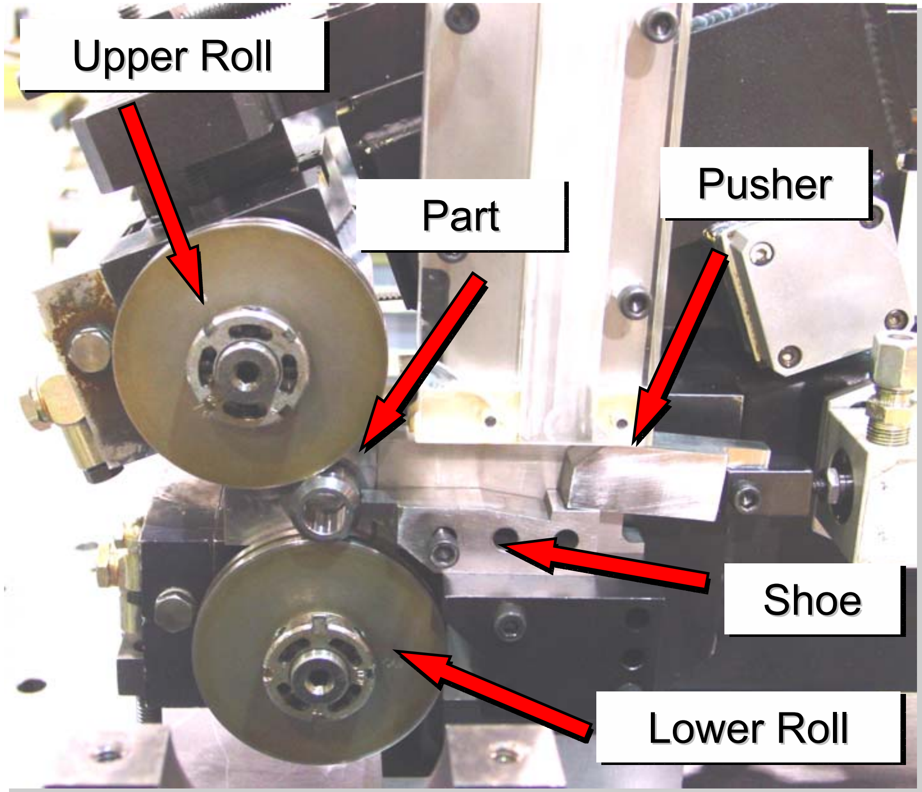
- ❖ Evaluate the possibilities and limitations to implement the chatter detection directly in the grinding machine.

The prototype machine will be built using the same fixture and the same measurement system already present in the grinding machine.

Roll-Shoe Centerless Fixture

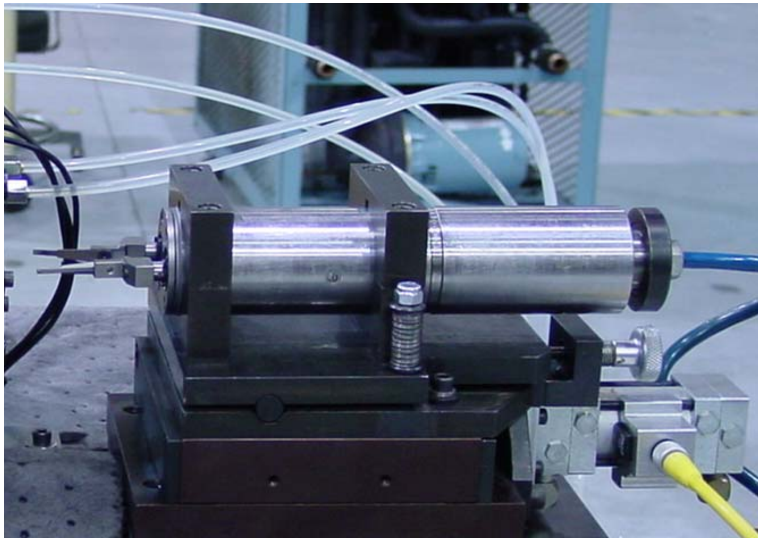
❖ Properties

– Prototype of the fixture used in the grinding machine
– Part position is defined by two rolls and a shoe
– Part rotated by the two rolls
– Hydrostatic bearings for roll spindles
– Part ejected by pusher
– Pusher and upper roll actuated by hydraulic cylinders



Marposs Thruvar 5 Gage Head

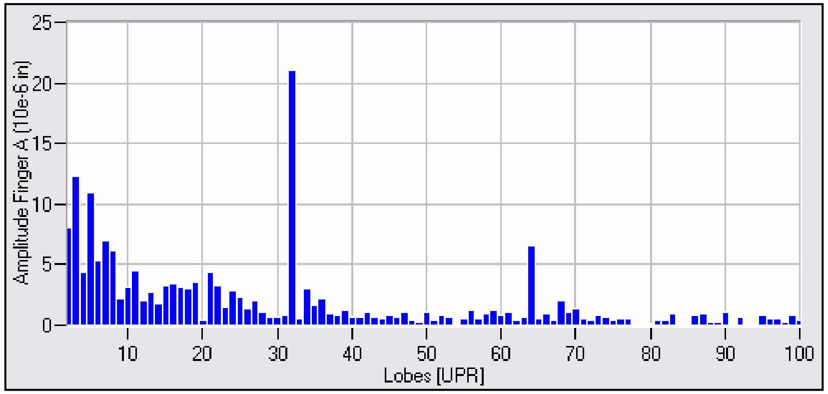
- Gage Head Properties
  - Two diamond tipped fingers trace the inner diameter of the part
  - Two LVDTs to convert finger displacement into electrical signal
  - Cut-off frequency of 220 Hz [*Longanbach, Kurfess 2001*]



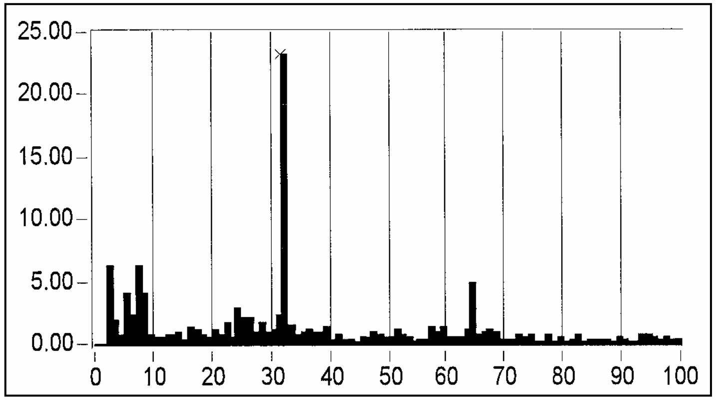
- Calibration
  - Fingers are calibrated using direct calibration
  - Theoretical measurement resolution with 16 bit DAC input 4.6 nm
  - 1940 data points per workpiece

Preliminary Results

- Comparison with roundness machine
  - Measurement of a part with chatter at 32 UPR



Prototype machine



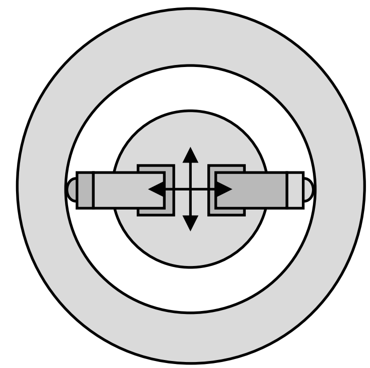
Roundness machine

- Results:
  - Machine is able to measure chatter
  - Deviations visible due to noise in the system

Main Reasons for Deviations

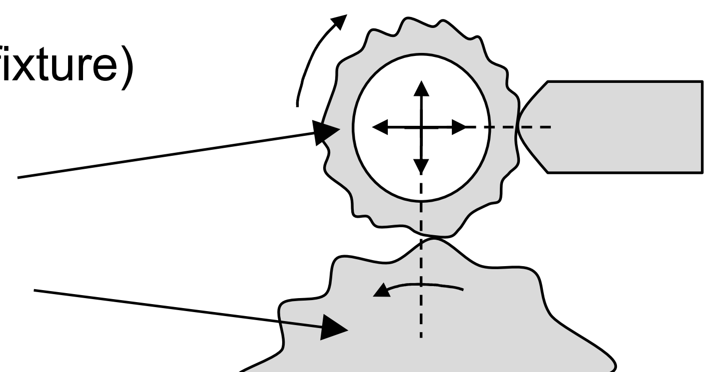
- Electrical Noise
  - EMI/RFI, magnetic fields, ground loops, fluctuation of power supply voltages
  - Randomly distributed according to normal distribution
- Forced Vibrations

  (movement between gage and fixture)
  - Pulsation of hydraulic fluid
  - Roll motor
  - Environment



- Centerless Fixture

  (movement between part center and fixture)
  - Roundness error of the part outer diameter
  - Roundness error of the rolls



Accuracy Improvement

<table>
<tr><th>Type</th><th>Source</th><th>Prototype Machine</th><th>Grinding Machine</th></tr>
<tr><td rowspan="6">random

deterministic</td><td rowspan="2">Electrical Noise</td><td colspan="2">Shielding and grounding techniques</td></tr>
<tr><td colspan="2">Averaging over multiple revolutions</td></tr>
<tr><td rowspan="3">Forced Vibrations</td><td>Hydraulic accumulators</td><td rowspan="2"></td></tr>
<tr><td>Vibration isolation system</td></tr>
<tr><td colspan="2">Analytical method to separate movement between part and gage from part profile</td></tr>
<tr><td>Workpiece Fixture</td><td>Shoe Design</td><td></td></tr>
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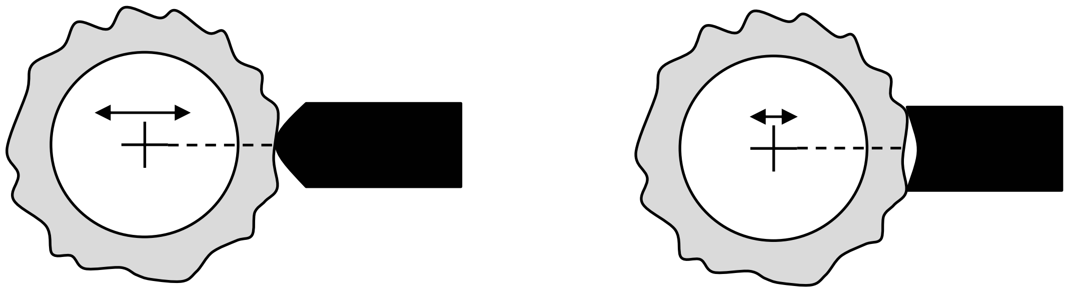
Shoe Design

- Exact shape of the shoe can lower the influence of the outer diameter
- Example:



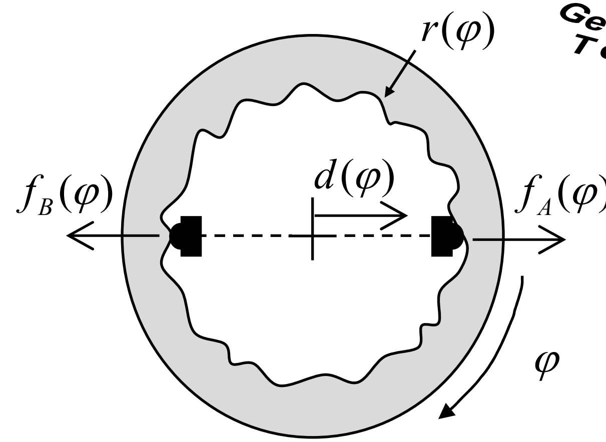
Large movement of the workpiece center due to OD

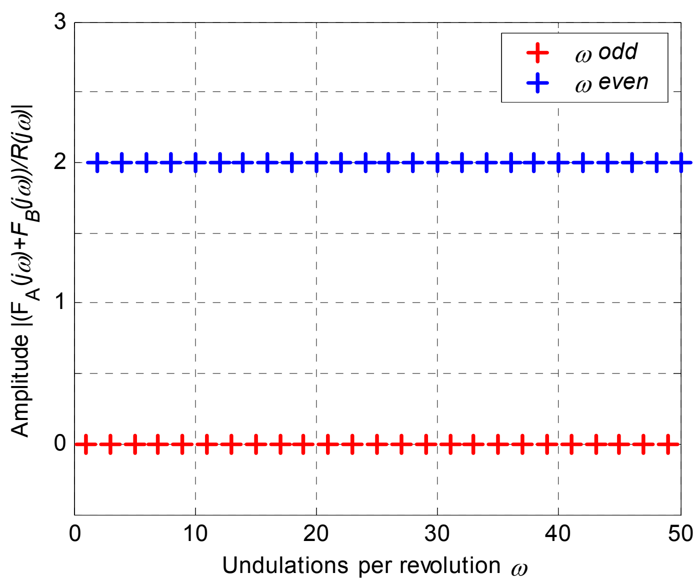
Smaller movement of the workpiece center due to OD

- Shape of the shoe acts as a low pass filter for the workpiece OD profile

Vibration Separation

- Input Variables
  - Profile $r(\varphi)$
  - Displacement relative to gage $d(\varphi)$
- Measured Finger Signals
  - Finger A $f_A(\varphi) = r(\varphi) + d(\varphi)$
  - Finger B $f_B(\varphi) = r(\varphi - \pi) - d(\varphi)$
  - Sum A+B $f_A(\varphi) + f_B(\varphi) = r(\varphi) + r(\varphi - \pi)$
- Amplitudes of odd frequencies cancel out
- Odd frequencies cannot be separated





Vibration Separation

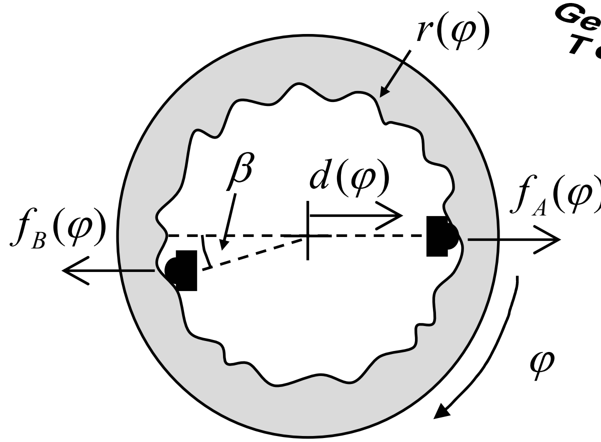
- Angle less than 180º
  - Finger angle β
- Measured Finger Signals

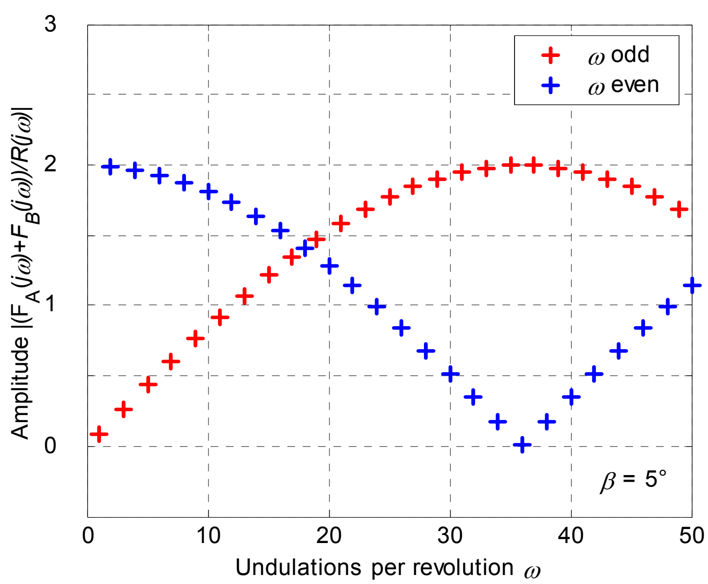
$$f_A(\varphi) = r(\varphi) + d(\varphi)$$

$$f_B(\varphi) = r(\varphi - \pi + \beta)\cos\beta - d(\varphi)$$

$$f_A(\varphi) + f_B(\varphi) = r(\varphi) + r(\varphi - \pi + \beta)\cos\beta$$

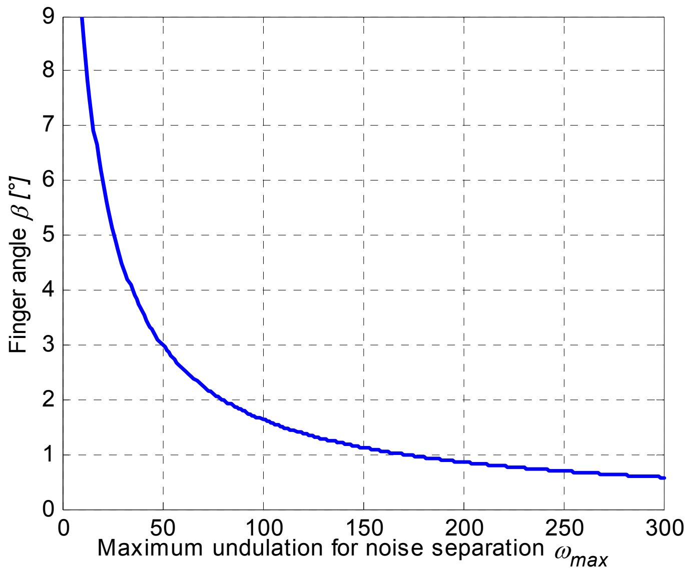
- Amplitudes are non-zero for a certain range
- All frequencies may be separable





Vibration Separation

Optimal finger angle β to filter undulations from 10 to ω_{max}



Limitations/Difficulties

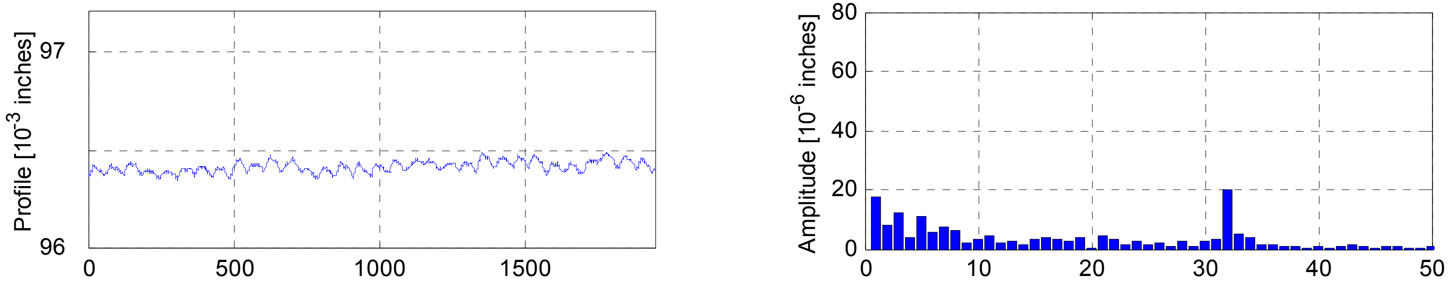
- Exact angle between fingers not known or not repeatable
- Workpiece slipping
- Effect of vertical vibration of the workpiece
- Random noise

Model of the workpiece in the fixture that incorporates these factors and allows statement about the accuracy of the vibration separation method

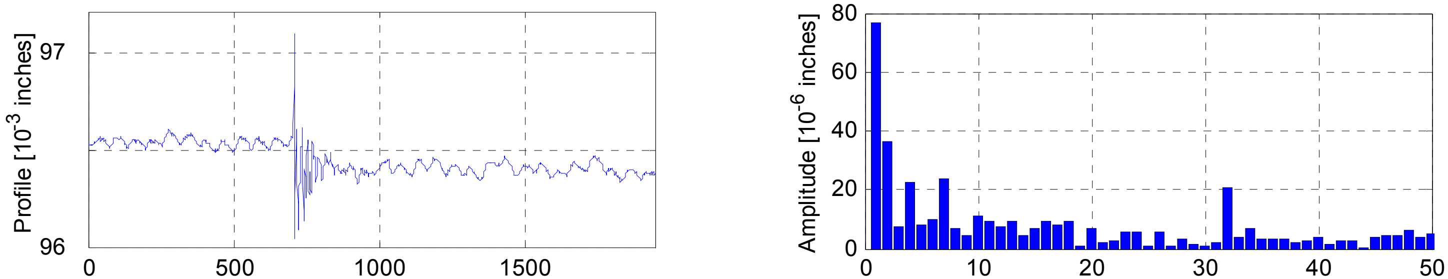
Experimental Results

Configuration with β =0º (separation for even lobes only)

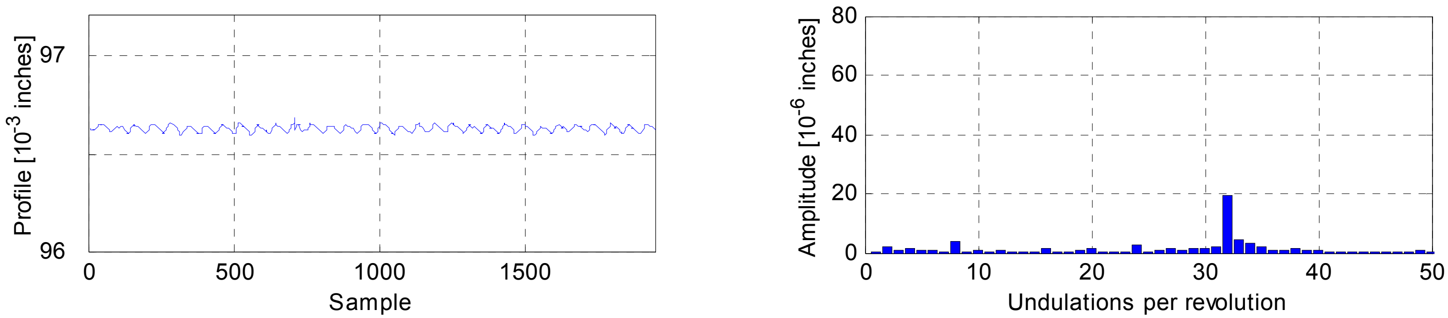
Measurement of a part with chatter at 32 UPR



Machine excited by an impulse during measurement



Filtering of the vibration



Expected Contributions

- Measurement of chatter on the inner diameter of the workpiece using an in-process gage and a roll-shoe centerless fixture
- Model of the workpiece in the roll-shoe centerless fixture including parameters such as slippage and vibration
- Evaluation of the accuracy of vibration separation from the profile with only 2 fingers
- Evaluation of the possibility to detect chatter directly in the grinding machine